

Tuesday: Conclusions and discussion (3 pages)

What have we seen?

Studied quantisation of relativistic bosonic string

spectrum of states: tachyon

massless gauge field (open)

graviton, 2-form, scalar (closed)

$\infty$  tower of massive higher spin fields

consistency including Lorentz invariance

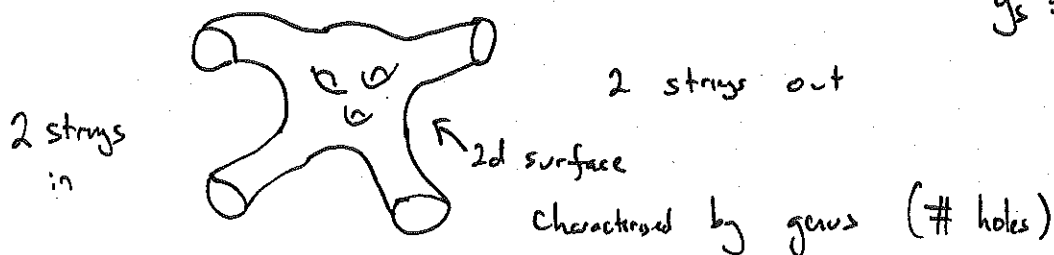
$$\Rightarrow D=26$$

could also study: i) string scattering

string coupling

$$g_s = \langle e\Phi \rangle$$

dynamical



scattering amplitudes finite at high energies (unlike particles)

ii) low energy approximation

n units  $c = \hbar = 1$   $[E] = L^{-1}$

low energy  $\leftrightarrow$  large distances

from large distance out, string looks like point particle

energies  $\ll$  mass of 1st massive string state  $\rightarrow$  only massless states (+ tachyon)

get conventional field theories (describe pt particles)

for bosonic string, closed  $\Rightarrow$  interacting graviton, 2-form scalar

$$S_{\text{low-energy}} \sim \int d^{26}x \sqrt{|g|} \left( R - \frac{1}{12} H^2 + 4(\partial\phi)^2 \right) e^{-2\phi}$$

$\nearrow$  Ricci scalar (Einstein-Hilbert)       $\nwarrow$   $H_{\mu\nu\rho} = 3\partial_{[\mu} b_{\nu\rho]}$  field strength

open  $\Rightarrow$  massless gauge field

$$S_{\text{low-energy}} \sim \int d^{26}x \left( -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} \right)$$

$$F_{\mu\nu} = 2\partial_{[\mu} A_{\nu]}$$

Problems: i) tachyon  $\Rightarrow$  theory is unstable

ii) no fermionic excitations

iii)  $D=26$  (?)

Solve i) and ii) using superstrings

g carry also fermionic excitations on worldsheet

$$\Rightarrow D=10$$

supersymmetry in spacetime, no tachyon  
(symmetry between bosons and fermions)

3

5 distinct superstring theories

|                        |                             |
|------------------------|-----------------------------|
| type IIA, IIB (closed) | heterotic $SO(32)$ (closed) |
| type I (open)          | heterotic $E_8 \times E_8$  |
|                        | $\uparrow$                  |
|                        | spacetime gauge symmetry    |

now know all can be related to each by dualities

eg type I at small coupling  $\Leftrightarrow$  het  $SO(32)$  at large coupling

eg IIA on circle of radius  $R \Leftrightarrow$  IIB on circle radius  $\frac{\alpha'}{R}$

and viewed as different limits of ~~string theories~~ M-theory (11-dim)

eg M theory on circle of radius  $R \Rightarrow$  IIA

at least  
sometimes

Ultimate formulation - still not known?